The Role of Supplementary Cementing Materials in Reducing the Effects of Alkali-Aggregate Reactivity: CANMET Investigations

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ABSTRACT

The effect of mineral admixtures in reducing expansion of concrete from alkali-aggregate reaction is being investigated. A total of 15 fly ashes, slags, silica fumes and natural pozzolans were chosen, to have a wide range in physical-chemical features of additives commercially available in Canada. One reactive carbonatic and two reactive siliceous aggregates were used.

This paper reports test data on the materials used, the performance of concretes containing each admixture in different proportions, and 12-month expansion measurements of mortar bars and concrete prisms made with them. The data are used to indicate optimum replacement levels and determine the effectiveness of the different admixtures in reducing deleterious reactions.

INTRODUCTION

The principal manifestation of A-A-R is the formation of expansive phases that destroy cement matrix bonds or cause destructive fracturing to relieve internal stress generated by expanding reaction products. The reactions have been studied by many (2, 4, 7), and methods developed that reduce harmful reactivity (Grattan-Bellew, 1983; Pepper and Mather, 1959).

One method of controlling reactions and extending the life of structures is to use additives that deactivate harmful cement compounds or at least reduce the rate of a reaction that produces expansive phases. This study examines the effectiveness of different additives in decreasing the expansion of concretes containing three known types of alkali-reactive aggregate. It is a CANMET investigation being made at the Canada Cement Lafarge research laboratory in Montreal.

MATERIALS AND PROCEDURES

Aggregates

The aggregates used were chosen to represent three rock types that have been found deleterious wherever the environment favours alkali-aggregate reaction:

1) rock containing unstable silica phases (opaline or poorly crystallized silica) that produce the classic alkali-silica reaction. The material used is an argillaceous limestone from the St. Maurice quarry at Trois-Riviéres, Quebec containing dispersed sub-micron, siliceous material and silicified fossils, evidently the reactive phases (Bérard, 1985);

2) argillaceous dolomitic limestone containing unstable dolomite and perhaps metastable constituents that would react with cement alkalis during de-dolomitization (Gillott, 1975). The rock used was obtained from deleterious layers in an aggregate quarry near Kingston, Ontario (Rogers, 1985);

3) silicate rocks containing unstable, mostly unidentified phases that are slowly reactive in and cause expansion of concrete, but do not yield an abundance of siliceous gels. The rock used is from a reactive band in moderately metamorphosed argillite at the Lady Evelyn Lake dam site near Cobalt, Ontario.

Standard petrographic and electron microscope techniques were used to examine the rocks and reaction products. Potential reactivities of the aggregate samples were tested by the chemical method (ASTM C-289) and an osmotic cell test (Stark, 1983).

Cement and Pozzolanic Admixtures

Cement used for the tests, ASTM Type 10 from Bath, Ontario, contained 1.1% Na_2O equivalent, including 0.6% soluble alkali.

Thirteen admixtures were used first: six fly ashes from different thermal plants, three granulated blast furnace slags, two condensed silica fumes, and two natural pozzolans. The fly ashes range widely in chemical and phase composition, particle size and particle density. The slags and silica fumes differ greatly in chemistry, less in morphology. The natural pozzolans are quite different, the Quesnel being a fragmental, glassy volcanic ash and the Amherst a diatomaceous earth. The pozzolanic activity of each additive was tested (ASTM C-311), and its ability to reduce alkali-aggregate reactivity was determined using pyrex glass as reactive aggregate (ASTM C-441). Chemical, physical, and reactivity data are given in Table 1.

The proportions of additives used to replace cement varied from 10 to 65 per cent.

Concretes and Mortars

Thirty mortar bars were made with pyrex glass to test how effectively the additives reduce A-A reactivity (ASTM C-441).

About 150 mixes were made with each aggregate to prepare mortar bars (ASTM C-227), concrete prisms (CSA 23.2-14A) and control specimens for testing strength and measuring expansion to determine the effectiveness of the additives in reducing alkali reactivity of the three aggregates. The water content of mixes was held at 48% of the weights of cementitious materials. Compressive strengths of the concretes were obtained on 100x200 mm cylinders at 28 days and 3 months of curing. Concrete prisms were held at 23°C, the mortar bars at 38°C to accelerate reaction. The specimens were kept in moist rooms at +95% R.H.

RESULTS AND CONCLUSIONS

Both the potential alkali reactivity (ASTM C-289) and the PCA osmotic cell tests indicated that only the Kingston dolostone would be deleterious; alkali reactivity of both the siliceous limestone and the argillite appeared too low to cause harmful

Table 1. Additives: Chem-Phys. Features, Activity#, Exp'n Reduc'n*

Source	Main Features	Blaine, cm^2/g $x10^3$	Alkali %	Pozz. Activ.	Exp'n Red'n,%
Fly Ashes					
Lingan, N.S.	Low CaO	3.19	2.62	94	70.1
Dalhousie, N.B.	Low CaO; Fe	2.22	1.15	90	47.8
Lakeview, Ont.	High Carbon	4.88	1.58	89	62.2
Estevan, Sask.	High alkalis	3.25	7.81	95	67.7
Thunder Bay, Ont.	High sol. alk	6.12	6.78	141	85.1
Sundance, Alta.	Medium CaO	3.60	2.00	80	50.2
Silica Fumes					
SKW; Trois-Riv. Que	High silica	-	.51	119	104.5
Chromasco, Que.	Lower silica	-	2.60	93	99.0
Slags					
Standard Slag; Ont.	Variable in	4.2	.64	~	77.6
Atlantic Slag; N.Y.	chem. comp.	5.98	.30	~	66.2
Natural Pozzolans					
Amherst, N.S.	High silica	28.89	.06	82	95.0
Quesnel, B.C.	Low silica	7.67	5.52	95	79.6

ASTM C-311: Pozzol. activity * ASTM C-441: Expans'n red'n with pyrex
~ Both slags are cementitious

expansion of concrete from A-A reactions. Moreover, expansion fractures and alteration phenomena occurred only on the Kingston the Kingston control specimens. Electron microscopy of the other concretes showed no sign of reaction at aggregate boundaries or in pores.

Concrete Expansion Tests

The influence of the different types and amount of admixture on the expansion of concretes containing these rocks is revealed in Figs. 1 & 2, which show histograms of the expansion of mortar bars and concrete prisms at an exposure period of 1 year. Only the maxima and combined average values of per cent reduction of expansion by the four different types of admixture were plotted. Mortar bar tests were not made with the Kingston dolostone, as the test is not effective with the alkali-carbonate reaction.

The concrete prism tests, like the reactivity tests, indicate that only the Kingston dolostone should cause deleterious expansion of concrete; control prisms containing the siliceous aggregates expanded little or not at all. The mortar bar tests,conversely, indicate that the Lady Evelyn Lake meta-argillite could also be sufficiently alkali reactive to harm concrete, but not the siliceous Trois-Riviéres limestone.

The effectiveness of different additives in reducing alkali rectivity of these three aggregates is relatively clear:

Kingston Dolostone: 1) Only particular fly ashes (maxima plots) in excess of 30% could reduce expansion of dolostone concrete prisms to below a nominally "safe" 0.04% at one year's exposure; 2) silica fumes would not reduce expansion sufficiently even at 15% cement replacement; 3) the minimum of 35% slag reduced expansion to a possibly tolerable level; 4) one natural pozzolan (Amherst diatomite) reduced dolostone concrete expansion effectively at 10% replacement, the other at 20%.

L.E.L. Meta-Argillite: 1) With few exceptions, fly ashes increased the reactivity of Lady Evelyn meta-argillite at less than 30% replacement, and some may still be ineffective as reducers above that level; 2) silica fumes, slags and natural pozzolans behave similarly, and may be effective only above the 10%, 50% and 20% replacement level, respectively.

Trois-Riviéres Limestone: Although the control tests indicated the limestone was innocuous, some additives affected expansion, particularly of mortar bars. 1) Some fly ashes and the natural pozzolans increased reactivity, possibly deleteriously, with low replacement content but decreased it with higher content; 2) silica fumes and slags had little apparent effect on mortar bar expansion but slightly increased the expansion of prisms.

The investigation has revealed the need of careful study to classify aggregates according to their alkali reactivity and interpret test results intended to reveal it. Only two of these three known reactive aggregates were shown by standard tests to be potentially reactive. The samples of Trois-Riviéres limestone used were either unreactive or too slowly reactive for the tests, even though the rock had proved deleterious in field concrete. Both mortar bar and concrete prism tests were needed.

The expansion tests revealed the effectiveness of different additives in reducing A-A-R of the different rocks and the variation of effectiveness within additive types. The efficiency of the slags and the diatomite in reducing reactivity of the dolostone is most notable.

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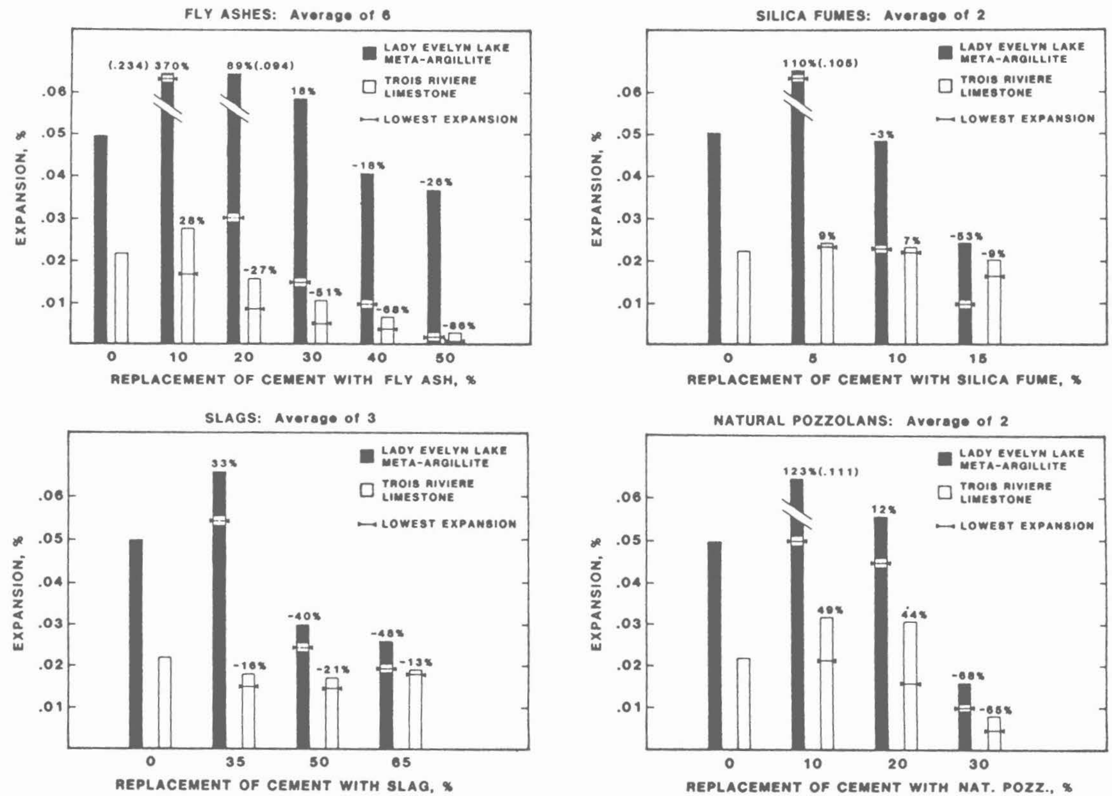

Fig. 1 - Influence of different additives on 12-month expansion of mortar-bars (ASTM C-227) cured at 38°C. Shows averaged and maximum (<->) per cent expansion reduction values.

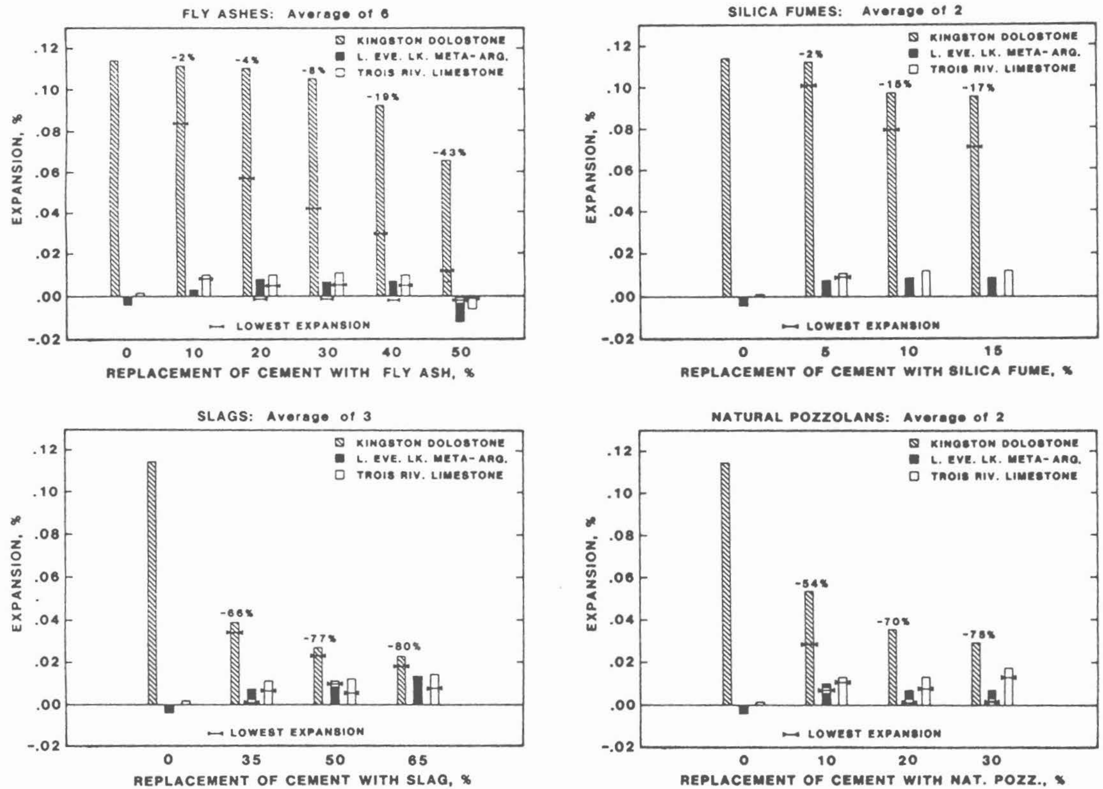

Fig. 2 - Influence of different additives on 12-month expansion of concrete prisms (CSA 23.2-14A) cured at 23°C. Shows averaged and maximum (>-<) expansion reduction values.